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Retroactive interference effects of mentally imagined movement speed

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In two retroactive interference experiments, we assessed the effect of mentally imagined movement speed on subsequent motor performance. All participants performed a sequential motor action at three speeds during a baseline test and a retention test. During the retention interval of Experiment 1, the participants ($n = 50$) physically performed the action at a slow speed, physically performed it at a fast speed, imagined it at a slow speed, imagined it at a fast speed, or performed a no-practice control task. In Experiment 2, the participants ($n = 24$) imagined the movement, overtly vocalized words, or both, all at a slow speed. The results revealed that the speed of the imagined motor action affected the speed of subsequent performance in the retention test and that imagery and physical practice were functionally equivalent. The results are consistent with Lang's bio-informational theory.

Keywords: bio-informational theory, imagery, retroactive interference, speed, sport psychology.

Introduction

In sport psychology, it is generally recommended to apply imagery in real time, at the speed at which athletes actually perform the actions (Nideffer, 1985; Weinberg and Gould, 1995; Gould and Damarjian, 1996). However, the theoretical foundation and the empirical evidence that substantiates this advice are limited, and it is not unusual in sports to imagine a skill in slow motion. For instance, Tomas Gustafson, a Swedish speed skater, used to imagine his movement patterns at slow speed outside the skating-rink (Hermansson, 1989). Here, we examine possible interfering effects of imagined movement speeds on subsequent movement performance and provide an explanation based on Lang's (1977, 1979, 1984, 1987) bio-informational theory of emotional imagery. Bio-informational theory offers an elaborate explanation of the processes involved in imagery (see Hecker and Kaczor, 1988; Bakker *et al.*, 1996) and appears to be particularly suitable for explaining interference effects on motor actions. Even though Lang's theory does not specifically address the

topic of interference of motor imagery, the theory does permit predictions about it.

According to bio-informational theory, each image structure contains three fundamental classes of coded information (Lang, 1984, 1987; Cuthbert and Lang, 1989; Hale, 1994; Drobles and Lang, 1995): stimulus propositions, response propositions and meaning propositions. *Stimulus propositions* refer to the scenario or event to be imagined and describe the objective properties of a specific stimulus feature (i.e. the stimulus context). *Response propositions* contain modality-specific assertions about behaviour, such as verbal responses, motor actions or visceral responses. Response propositions are of particular importance because they are double-coded; beyond the associational or propositional networks, the deep structure of such propositions is linked to the motor command system that generates efferent output. Because of this link between response propositions and motor programmes, imagery normally involves efferent leakage, which might be assessed by EMG recordings (see Bakker *et al.*, 1996). *Meaning propositions* are associative properties that elaborate upon the significance of stimulus and response information. These properties play an analytical and interpretative role by defining the meaning of input and output events, the probability of stimulus occurrence

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and the consequences of an action. Meaning propositions represent information that is not objectively present in the stimulus context. These three propositional constructs are the basic units of a preparatory set to respond; that is, they form an information network that constitutes a prototype for overt behaviour (a response prototype). Such a propositional network can be reactivated and processed by using a set of three primary imagery instruction elements (Lang *et al.*, 1980, p. 180): '1) an image *cue*, the simple instruction to generate an image; 2) the image *orthesis*, a more or less elaborate description of the things to be imagined; and 3) instructions to take an *action set*, that is, to imagine oneself as personally engaged in the image context, "as if" it were really happening'. For the application of imagery, this means that, to enhance the efficacy of imagery, the image cue, orthesis and action set provided to an athlete should include not only stimulus propositions but response and meaning propositions as well. In addition, Hecker and Kaczor (1988) reported that processing occurs only when a critical number of propositions are accessed, indicating that imagery will only result in a behavioural change when the image is vivid.

The aim of the present study was to assess the effect of the speed of an imagined movement. If movement speed can be regarded as a significant feature of actions, it will be represented in some way within the informational network. When movement speed is propositionally encoded, imagery can and will modify the temporal aspects of this informational network. This implies that the network can be modified in two directions – its propositions can reflect the motor action at a faster or a slower speed, depending on the imagined movement speed. Imagery of a motor action at a specific speed will result in speed-specific interference to a subsequently performed motor action.

The speed at which a movement or a series of movements is performed is important. Movement speed sometimes distinguishes between actions of the same class and can be considered a demarcation criterion for motor actions. For example, moving your feet at a low or high speed towards an incoming ball will result in stopping or kicking the ball, respectively. Movement speed should therefore be regarded as a distinct and relevant feature of action that is encoded within a propositional network. Indeed, Sirigu *et al.* (1996) demonstrated excellent congruence between maximum imagined and executed movement speed, indicating that normal individuals are able to imagine a motor action quite accurately at a specific speed. The speed of an imagined action might be encoded in the response, meaning or stimulus propositions of the preparatory set, which will function as a speed-specific response prototype for overt behaviour.

We report two experiments that used a retroactive interference paradigm. Several researchers have shown interference effects of interpolated *physical* activity on performance of a criterion motor task (see Magill, 1989; Schmidt and Lee, 1999). There is evidence to suggest that recall of the criterion task shifts in the direction of the interpolated activity (Craft and Hinrichs, 1971; Stelmach and Walsh, 1972). When, for instance, the interpolated activity is a movement of greater amplitude than the criterion movement, then the amplitude of the criterion movement at the retention test will tend to increase, whereas an interpolated movement of smaller amplitude will tend to cause the amplitude to decrease during the retention test. This direction-specific biasing effect is known as the 'assimilation tendency'.

Several studies (Johnson, 1982; Gabriele *et al.*, 1989; Hall *et al.*, 1995) have shown that *imagining* a motor performance can also interfere with a subsequently performed movement. Using a linear positioning task, Johnson (1982) showed that interpolated imagery resulted in an assimilation tendency for movement amplitude (or movement length), suggesting a functional equivalence between imagery and physical practice. Gabriele *et al.* (1989) showed that this similarity also holds for contextual interference. Hall *et al.* (1995) provided further evidence for the functional similarity of imagery and physical practice using retroactive interference. These authors showed that the amount of imagery or physical practice during the retention interval affected the magnitude of the interference effect. However, all of their groups, including the imagery groups and the rest group, received interpolated *physical* practice trials as well. Therefore, any interference effects found for the imagery groups might be the result of the received interpolated physical practice. They found that more interpolated imagery or physical practice caused poorer movement pattern retention (there was a larger interference effect) than less interpolated practice. Additionally, imaging a faster performance during the retention interval resulted in a faster subsequent performance. This finding suggests that, for the temporal aspects of a movement, there is a similarity between interpolated imagery and physical practice, although the results do not permit conclusions to be drawn regarding possible interference effects of imagined movement speed.

To date, the tasks used to investigate interference of motor imagery have been elementary motor tasks, typical in a laboratory setting, but they do not resemble the complexity of common actions in sport. In the present study, interference effects were investigated using a more complex motor task, corresponding, for instance, to sequential motor actions of a gymnastic

floor exercise, the learning of a feint in soccer or basketball, the fixed step pattern of a high-jumper in track and field events, or a step sequence in a salsa, a foxtrot or a waltz.

In summary, if a motor action is imagined, this might modify the propositional network. The modified network or prototype for overt behaviour will reflect the characteristics of the imagined motor action. For instance, when during imagery the movement amplitude or length (see Johnson, 1982) or movement pattern (see Gabriele *et al.*, 1989; Hall *et al.*, 1995) is different from the preceding performance, then the propositions in the information network will change accordingly. Such a modified network is assumed to alter subsequent performance.

Experiment 1

Based on Lang's theory we assumed that: (1) an imagined variant on an action will interfere with the subsequent execution of that action, and (2) that this interference will reveal an assimilation effect (i.e. it will be speed-specific). We hypothesized that interpolated imagery of a sequential motor action at a fast speed would lead to faster performance of this movement during a retention test, and that interpolated imagery of the same task at a slow speed would lead to slower performance in the retention test. We also predicted that interpolated imagery would result in interference effects similar to those of interpolated physical performance, which would provide further evidence of functional equivalence between imagery and physical practice of movement speed.

Methods

Participants

Fifty undergraduate or recently graduated students (22 males, 28 females) took part in the experiment (age 26.1 ± 4.6 years; mean \pm s). All participants were naive to the aims of the experiment and were paid for their participation.

Experimental task

Figure 1 is a diagram of the sequential motor action used in this study. One complete sequential motor action (one trial) consisted of a sequence of 12 rhythmic steps performed within a square drawn on the floor. At the beginning of the experiment, the sequential motor task was demonstrated by the experimenter and practised by the participants for 1 min. After this short practice, all participants were able to perform the 12 steps of the motor action in the correct sequence. To account for individual differences in comfortable stride length, the sides of the square were adjusted to the participant's leg length (measured from the trochanter major to the malleolus lateralis). The mean length of the sides of the square was 0.9 m.

Apparatus and instrumentation

For all participants, EMG signals were recorded from the tibialis anterior of the right leg using standard disposable Ag/AgCl surface electrodes, applied over the origo and insertio sides of the muscle, and a reference or ground electrode attached to the lateral ankle. However, analysis of the amplitude and frequency of the EMG

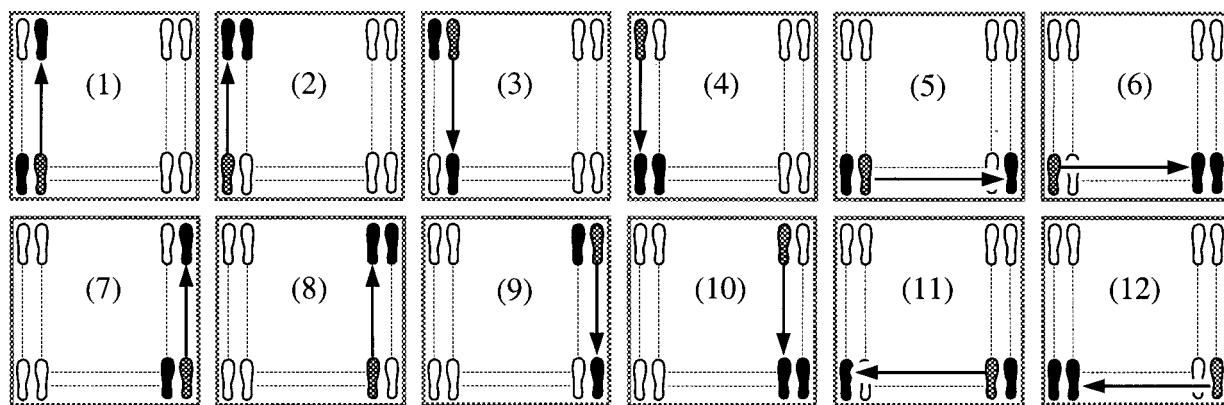


Fig. 1. Schematic representation of the 12 steps of the sequential motor task. The black footmarks represent the location of the feet; the dotted footmark represents the initial location of a foot before moving. At the starting position, the participants stood with both feet in the lower left position. The participants started the sequential motor actions by moving their right foot forward (1), then their left foot forward (2), then their right foot backward (3), etc. They ended one motor action by moving their right foot sideways (12). The subsequent sequential motor task (starting with 1 again) was executed directly after the last step (12). There was no delay between step 12 and step 1 of the subsequent task.

signals during physical performance did not reveal any differences among the three walking speeds. That is, the EMG signals were unable to discriminate among the three different movement speeds; therefore, no further EMG analysis was conducted.

Foot-floor contact and the movements of the legs of the participants up to the hip were recorded using a standard VHS video camera at a sampling rate of 25 Hz. The camera was located 3.5 m behind the participant (placed about 0.2 m above the floor). To assess movement duration, a time-code generated by an Alpermann+Velte TC 30 Generator was added to the videotapes.

To determine the imagery ability of the groups, the shortened version of the Dutch Movement Imagery Questionnaire (see Hall and Pongrac, 1983; Goss *et al.*, 1986; Schattel, 1992) was used. This version of the questionnaire consists of six items designed specifically to measure imagery of movements and contains scales for measuring visual and kinaesthetic imagery ability. The difficulty participants experienced in imagining the movements was indicated on a 7-point rating scale, ranging from 1 ('easy to imagine') to 7 ('difficult to imagine'; Goss *et al.*, 1986). The reliability of the Dutch version of the questionnaire is good. Cronbach's alpha internal consistency coefficients are 0.90 (visual subscale) and 0.91 (kinaesthetic subscale). The test-retest reliability of the subscales is $r = 0.83$ and $r = 0.75$ respectively at an interval of 3 weeks (Schattel, 1992). Alphas of the shortened versions are 0.88 (visual subscale) and 0.85 (kinaesthetic subscale). Additionally, information was gathered concerning the participants' sporting activities and their everyday use of imagery during the previous year.

Treatment groups

The participants were randomly assigned to one of five groups that differed in the activity to be performed during the retention interval, each of which contained 10 individuals:

1. Physically perform the sequential motor action at a slow speed (slow physical, PS); 5 males, 5 females.
2. Physically perform the sequential motor action at a fast speed (fast physical, PF); 3 males, 7 females.
3. Imagine the sequential motor action at a slow speed (slow imagery, IS); 5 males, 5 females.
4. Imagine the sequential motor action at a fast speed (fast imagery, IF); 4 males, 6 females.
5. A control group (C) that received an interpolated no-practice task; 5 males, 5 females.

At the beginning of the experiment, the imagery groups (IS and IF) received instructions regarding: (1) what is meant by 'imagery'; (2) that imagery is an

effective technique for practising motor skills; (3) that it is applied by many elite athletes; and (4) to create an impression that is as vivid as possible, one has to use all one's senses (i.e. imagine the visual, auditory, haptic and kinaesthetic characteristics of the movement).

Procedure

The participants were tested individually in a quiet room. To prevent any distraction during the experiment, opaque screens limited the participants' visual field. After outlining the experimental design to the participants, they completed an informed consent form and answered questions regarding personal characteristics (i.e. name, age and sex). The procedure of the experiment and the criterion task were explained, although no information was provided about possible retroactive interference effects or about the variables to be assessed. Standardized instructions were provided during the experiment. The experiment consisted of three phases: baseline test, retention interval and retention test (see Table 1).

Baseline test. In the first phase of the experiment, all participants performed the sequential motor action at three different speeds: the preferred speed of the participant, about two times slower and about two times faster than their preferred speed. The participants were instructed not to perform the 'fast speed' condition at their maximum speed, to prevent a ceiling effect and to enable a faster performance of the 'fast speed' condition during the retention test. The participants chose the three speeds themselves, not with the

Table 1. Design of Experiment 1

Groups	Baseline test ^a	Retention interval ^b	Retention test
PS	P ₁ -F-P ₂ -S	Slow physical performance	P ₁ -F-P ₂ -S
PF	P ₁ -S-P ₂ -F	Fast physical performance	P ₁ -S-P ₂ -F
IS	P ₁ -F-P ₂ -S	Slow mental imagery	P ₁ -F-P ₂ -S
IF	P ₁ -S-P ₂ -F	Fast mental imagery	P ₁ -S-P ₂ -F
C ₁	P ₁ -F-P ₂ -S	Control task	P ₁ -F-P ₂ -S
C ₂	P ₁ -S-P ₂ -F	Control task	P ₁ -S-P ₂ -F

^a During the baseline test and the retention test, all participants performed the same sequential motor action (see Fig. 1), the same number of trials (five trials for each speed condition) and the same speed conditions. The speed conditions were presented in two different orders (P₁-F-P₂-S and P₁-S-P₂-F): 'P' is the preferred speed condition, 'F' is the fast speed condition and 'S' is the slow speed condition.

^b During the retention interval (or interpolated practice period), the participants either performed the sequential motor action at a slow (PS) or fast (PF) speed, imagined the sequential motor action at a slow (IS) or fast (IF) speed, or performed a control task (C).

aid of a metronome. The three speeds were performed in two different orders depending on group: preferred₁-fast-preferred₂-slow (P₁-F-P₂-S) and preferred₁-slow-preferred₂-fast (P₁-S-P₂-F). The groups performing the interpolated trials at a slow speed (PS and IS) and half the participants in the control group (C₁) received the 'P₁-F-P₂-S' order conditions. The groups performing the interpolated trials at a fast speed (PF and IF) and the other half of the control group (C₂) received the 'P₁-S-P₂-F' order of conditions. Consequently, the last speed condition in the baseline test was the same as the practice speed in the retention interval (except for the control group, who received no practice). A trial was defined as one complete sequential motor action of 12 steps. Each speed condition consisted of five successfully performed sequential motor actions or trials. When a participant made a mistake during the execution of the motor action, he or she immediately repeated the sequential motor action (resulting in an additional trial), thereby performing six sequential motor actions instead of five. More than one mistake was made in less than 5% of the speed conditions.

Retention interval. A fundamental tenet of bio-informational theory is that the imagery instruction (orthosis and action set) should be personalized to optimize the efficacy of meaning propositions. Smith *et al.* (1999) showed that the use of video (filmed from the perspective of the participant) is more effective in enhancing performance than a personalized written script or audio-tape. Therefore, at the beginning of the retention interval (the interpolated practice period), the participants in the two physical and two imagery groups were shown a video of their last trial during the baseline test, and were asked to perform (physical groups) or imagine (imagery groups) the sequential motor action at the speed they had just observed on the television screen.

At the beginning of each imagery trial, the participants in the two imagery groups were asked to close their eyes and to imagine the sequential motor action (i.e. the image cue), to imagine the steps of the sequential motor action at the speed observed in the video (i.e. the image orthosis), to visualize the movements as vividly as possible, and to imagine the kinaesthetic and haptic sensations when covertly performing the steps of the sequential motor action (i.e. the action set). The participants in the two imagery groups were instructed to use imagery in the way that was most comfortable for them. In addition, they were told that the instructor or experimenter would tell them when to start and when to stop the imagery session.

The participants in the two physical and two imagery groups practised the sequential motor action in five blocks of five successive trials. Between blocks, the parti-

cipants were allowed a short break of 1–1.5 min. For the participants in the imagery groups, the duration of an imagery practice block (five trials) during the retention interval was the same as the duration of the last speed condition in the baseline test (slow imagery group 51.7 ± 16.9 s; fast imagery group 27.8 ± 3.2 s; mean \pm s). The participants in the control group did not practise the sequential motor action; instead, they completed a standardized questionnaire.

Retention test. The retention test was identical to the baseline test for all participants in all groups.

Manipulation check. After completion of the retention test, a brief post-experimental interview was conducted. The participants in the imagery groups were asked if they had imagined the steps of the sequential motor action and if they had imagined the motor action at the instructed speed. The participants in the control group were asked if they had used imagery during the experiment. Finally, the shortened version of the Dutch Movement Imagery Questionnaire was administered.

Assessments

Five successive trials (sequential motor actions) were performed at each speed, but only the middle three trials were analysed (starting and finishing the motor action might have altered the duration of the first and last trials). The speed at which the sequential motor action was performed was measured as the time required to complete a sequential motor action – that is, the time to execute one trial. For each speed condition and participant, the mean time to complete a trial in the retention test was subtracted from the mean time to complete a trial in the baseline test, providing the constant error. The constant error represents the amount of interference produced by the interpolated practice. Comparison of the mean constant error between the imagery and physical practice groups reveals the functional similarity (equivalence or dissimilarity) of both types of practice.

Results

Characteristics of participants

Using three one-way analyses of variance, there were no significant differences between the five experimental groups on imagery ability (assessed using the shortened version of the Dutch Movement Imagery Questionnaire, MIQ) or on familiarity with and the daily use of imagery. The Dutch MIQ scores (ranging from 1 = 'easy to imagine' to 7 = 'difficult to imagine') for the five

experimental groups were: $MIQ_{PS} 2.6 \pm 0.95$; $MIQ_{PF} 2.5 \pm 1.14$; $MIQ_{IS} 2.8 \pm 1.47$; $MIQ_{IF} 3.0 \pm 1.23$; $MIQ_C 3.1 \pm 0.92$ (mean \pm s).

Effects of design and conditions

To check for possible effects caused by the two orders of speed conditions (P_1 -F- P_2 -S and P_1 -S- P_2 -F), a repeated-measures analysis of variance (ANOVA) was conducted on the mean time (T) to perform a trial at baseline, with order (P_1 -F- P_2 -S and P_1 -S- P_2 -F) as a between-individuals factor and speed condition (slow, preferred₁, preferred₂ and fast) as a within-individuals factor. This analysis showed the expected effect for speed condition ($F_{3,144} = 215.75$, $P < 0.001$, observed power = 1.00). Order did not result in a significant main effect ($F_{1,48} = 0.68$) and there was no significant interaction. *Post-hoc* analysis (LSD test, with a level of significance of 0.05) revealed a significant difference between the slow ($T_S = 10.04 \pm 2.50$ s), the preferred ($T_{P1} = 7.55 \pm 1.48$ s, $T_{P2} = 7.45 \pm 1.69$ s) and fast ($T_F = 5.53 \pm 1.22$ s) speed conditions. The speeds at which the preferred conditions were performed (P_1 and P_2) did not differ significantly. Although the participants did not perform the sequential motor action at a factor of two slower or faster than their preferred speed, they did perform the task slower and faster as instructed.

Retention interval and manipulation check

For the participants in the slow physical practice group, the mean time to complete one sequential motor action at the slow speed during the retention interval was 140% of the mean preferred speed (compared to 129% during baseline performance); the participants in the fast physical practice group

performed the fast speed at 67% of the mean preferred speed (compared to 71% during baseline performance). All participants in the two imagery groups reported that they imagined the steps of the sequential motor action at approximately the instructed speed, although several participants in the fast imagery group reported that it was difficult to imagine the action at the fast speed. None of the participants in the control group reported that they had used imagery during the experiment.

Effect of interference

To test the hypothesis that differences in speed during the retention interval would result in speed-specific interference effects, a repeated-measures ANOVA was performed on the constant error (revealing the amount of interference), with group (PS, PF, IS, IF and C) as a between-individuals factor and speed condition (slow, preferred₁, preferred₂ and fast) as a within-individuals factor. This ANOVA resulted in a significant main effect of group ($F_{4,45} = 5.01$, $P = 0.002$, observed power = 0.94) and a significant interaction of group and speed condition ($F_{12,135} = 1.95$, $P = 0.034$, observed power = 0.90). Table 2 shows the mean constant errors by group and by speed condition; Fig. 2 shows the effect of interference by group. A positive constant error indicates that, during the retention test, the sequential motor action was performed slower than during the baseline test, whereas a negative constant error indicates that the movement was performed faster during the retention test than during the baseline test. *Post-hoc* analysis (LSD test, with a level of significance of 0.05) on the main effect for group revealed that the two slow practising groups (PS and IS) were significantly different from the other three groups. The significant difference between

Table 2. Interference effects (constant error) of Experiment 1^a

Groups	Speed condition				Mean CE ^b
	Slow	Preferred ₁	Preferred ₂	Fast	
PS	951 \pm 1940	222 \pm 1063	335 \pm 852	475 \pm 304	496 \pm 946
PF	-887 \pm 874	-665 \pm 617	-693 \pm 492	-275 \pm 245	-630 \pm 456
IS	516 \pm 1330	598 \pm 1321	457 \pm 1108	462 \pm 929	508 \pm 1041
IF	-757 \pm 789	-396 \pm 557	-102 \pm 548	15 \pm 463	-310 \pm 476
C	-578 \pm 954	-37 \pm 530	-125 \pm 469	147 \pm 549	-148 \pm 356
Significance at $P < 0.05$	PS > PF, IF, C IS > PF, IF	PS > PF IS > PF, IF	PS > PF IS > PF	PS > PF IS > PF	PS > PF, IF, C IS > PF, IF, C

^a A positive constant error indicates that the sequential motor action is performed more slowly during the retention test than during the baseline test; a negative constant error indicates the opposite.

^b The last column reveals the main effect for group (see also Fig. 2).

Abbreviations: CE = constant error, PS = slow physical, PF = fast physical, IS = slow imagery, IF = fast imagery, C = control.

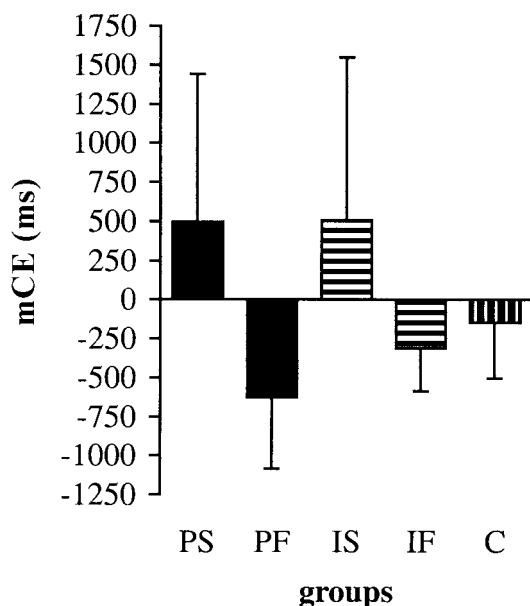


Fig. 2. Results of Experiment 1. Mean constant errors (mCE: average of the four speed conditions) for the five groups: physical practice at a slow speed (PS), physical practice at a fast speed (PF), imagery at a slow speed (IS), imagery at a fast speed (IF) and control (C).

the slow practising groups and the control group indicated the existence of an interference effect. Physically performing as well as imagining the sequential motor action at a slow speed resulted in a similar amount of interference (the size of the interference effect was similar, as was the standard deviation). The significant difference between the fast practising participants (PF and IF) and the slow practising participants (PS and IS) indicated an assimilation effect. For the fast imagery and physical practice groups (PF and IF), no interference was demonstrated, although for these groups the mean changes were in the expected direction (a decrease in the constant error).

A *post-hoc* analysis (LSD test, with a level of significance of 0.05) examining the two-way interaction between group and speed showed that, for all four speed conditions, there was a significant difference between both slow practising groups (PS and IS) and the fast physical group (see Table 2). Furthermore, for the slow and preferred₁ speed conditions, the slow imagery group was also significantly different from the fast imagery group; for the slow speed condition, the slow physical group also differed from the fast imagery and control groups. For the fast physical group, there was also a significant difference between both preferred speed conditions and the fast speed condition. For the fast imagery group, the fast speed condition was significantly different from the preferred₁ and slow speed conditions, while the preferred₂ speed condition differed

from the slow speed conditions. For the control group, a significant difference was found between the preferred₁ and slow speed conditions. For the slow practising groups (PS and IS), no differences between speed conditions were apparent.

Discussion

The aim of Experiment 1 was to test the hypothesis that interpolated practice in which participants imagined a simple sequential motor action at a slow or a fast speed would lead to changes of this sequential motor action in a subsequent retention test. We also hypothesized that interpolated imagery would result in interference effects similar to those of interpolated physical practice. The results supported both hypotheses. The analysis indicated an assimilation effect, in that the participants who imagined or physically performed the sequential motor action during the retention interval at a slow speed showed a reduction in speed during the retention test (relative to the baseline test), whereas the participants who imagined or physically performed the sequential motor action at a fast speed showed an increase in speed during the retention test. Both slow practising groups were significantly different from the control group, with the imagery and physical practice groups showing similar differences, indicating a distinct retroactive interference effect and functional equivalence of the two kinds of practice. However, for the fast practising groups, the effects were less pronounced. The relatively small effect for the fast imagery group compared with the fast physical group might suggest that imagining a motor action at a fast rate could be quite difficult (confirmed by the verbal remarks of some of the participants), at least more difficult than imagining it at a slow speed. In addition, the results indicated that, for the fast practising groups, the effects were predominantly found in the slow speed conditions, whereas no such difference between speed conditions was found for the slow practising groups.

Although participants in the imagery groups reported that they imagined the steps of the sequential motor action, a direct check was not possible. Covertly verbalizing the steps of the sequential motor action (during the retention interval) could have affected the retention test in the same way. For instance, it is well known that many dancers covertly count the steps when performing a dance. The same holds for some of the movements performed during floor exercises in gymnastics and for hurdle-racers in track-and-field events who count the steps between the hurdles. Therefore, it is conceivable that the participants in the imagery groups covertly counted the steps of the sequential motor action, instead of imaging them. If verbal rehearsal of the steps of a

sequential motor action leads to a similar interference effect as imagery in practice, then the conclusions of Experiment 1 are equivocal, and cannot be considered consistent with Lang's bio-informational theory. This issue was addressed in Experiment 2.

Experiment 2

The aim of Experiment 2 was to determine if the assimilation tendency also occurs when participants verbally rehearse the steps of the sequential motor action during the retention interval. Because pronouncing words out loud at high speed might be difficult, all experimental groups in Experiment 2 practised the interpolated trials at a slow speed. If verbal rehearsal yields an assimilation effect, then verbal rehearsal of the steps of the sequential motor action at a slow speed during a retention interval should lead to a slower performance of these movements during the retention test, relative to baseline performance.

Methods

Participants

Twenty-four participants (9 males, 15 females) took part in Experiment 2 (age 26.0 ± 4.67 years). All participants were naive to the aim of the experiment, did not participate in Experiment 1 and were paid for their participation.

Apparatus and procedure

The apparatus used in Experiment 1 was also used in Experiment 2. The Movement Imagery Questionnaire was not used and participants were not asked questions about their habitual use of imagery. The procedure of Experiment 2 was similar to that of Experiment 1. Participants were again tested individually, were given standardized instructions, provided informed consent and performed the same sequential motor action as in Experiment 1.

The participants were randomly assigned to one of three groups:

1. Imagine the sequential motor action at a slow speed (imagery group, IS).
2. Imagine the sequential motor action at a slow speed while pronouncing words out loud that were compatible with the steps (combination group, IVS).
3. Pronounce words out loud that were incompatible with the steps of the sequential motor action at a slow speed (verbal group, VS).

We assumed that pronouncing words out loud that were incompatible with the steps would prevent imagery of the sequential motor action. The baseline test and retention test were identical for all participants in all groups.

During the retention interval, the participants in the imagery and combination groups were instructed to imagine the movements as vividly as possible by using all their senses (see 'Procedure' section of Experiment 1). The participants in the combination group were also instructed to verbally rehearse the imagined movements using a string of words compatible with the steps of the sequential motor action (the IVS-string translates to: 'forward, closing up, backward, closing up, sideways, closing up, forward, closing up, backward, closing up, sideways, closing up'; see Fig. 1). The participants in the verbal group rehearsed the same set of one- or two-syllable words but in a different order, incompatible with the sequential motor action (the VS-string translates to: 'backward, sideways, forward, sideways, closing up, sideways, backward, sideways, forward, sideways, closing up, sideways'). As in Experiment 1, all participants received five blocks of five successive trials at the slow practice speed. Between each block, the participants were allowed a short break of 1–1.5 min. The dependent variables and data analysis were identical to those used in Experiment 1.

Manipulation check. After completing the retention test, a brief post-experimental interview was conducted with all participants. The participants in the imagery and combination groups were asked if they had imagined the steps of the sequential motor action and if they had imagined the motor action at the instructed speed. The participants in the verbal group were asked if they had used imagery during the experiment.

Results

Effect of speed conditions

To determine if the three groups were comparable at the baseline test and if the speed conditions were performed according to the instructions provided, a repeated-measures ANOVA was conducted on the mean time (T) to perform a trial at baseline, with group (IS, IVS and VS) as a between-individuals factor and speed condition (slow, preferred₁, preferred₂ and fast) as a within-individuals factor. This analysis only revealed a significant effect for speed condition ($F_{3,63} = 115.14$, $P < 0.001$, observed power = 1.00). No effect was found for group ($F_{1,21} = 2.10$, $P = 0.147$, observed power = 0.38) and there was no interaction.

Retention interval

During the baseline test, the mean time to complete one sequential motor action in the slow speed condition (for all groups) was 139% of the mean preferred speed; for the fast speed condition, it was 74%. During the retention interval, the mean time to pronounce the words of one trial (in the slow speed condition) was 183% of the preferred speed for the participants in the combined group and 128% for the participants in the verbal group, indicating that they did pronounce the words during the retention interval at a slow speed, as instructed. The participants in the imagery and combination groups reported that they imagined the steps of the sequential motor action at the slow speed. None of the participants in the verbal group reported that they had used imagery during the experiment.

Effect of interference

To establish if verbal practice, like imagery, also leads to an assimilation tendency, a repeated-measures ANOVA was performed on the constant error (CE), with group (IS, IVS and VS) as a between-individuals factor and speed condition (slow, preferred₁, preferred₂ and fast) as a within-individuals factor. There were significant main effects for group ($F_{2,21} = 5.30$, $P = 0.014$, observed power = 0.78) and for speed condition ($F_{3,63} = 3.04$, $P = 0.035$, observed power = 0.69); there was no significant interaction. *Post-hoc* analysis (LSD test, with a level of significance of 0.05) on group revealed a significant difference between the imagery group ($CE_{IS} 459 \pm 452$ ms) and the other two groups ($CE_{IVS} -249 \pm 668$ ms; $CE_{VS} -486 \pm 661$ ms). The combination and visual groups did not differ from one another, but both performed the sequential motor action faster during the retention test than the imagery group. These results provide further evidence for the speed-specific interference of imagery observed in Experiment 1. The second main effect indicated significant differences between the four speed conditions. However, because there was no interaction effect between group and speed condition, this main effect is of little relevance for the hypotheses tested.

Discussion

The aim of Experiment 2 was to determine if verbal rehearsal of the steps of the sequential motor action could have caused the retroactive interference effects found in Experiment 1. The results of Experiment 2 showed that verbally pronouncing a string of words at a slow rhythm did not result in an assimilation tendency.

In addition, the means of the combination and verbal groups were in the opposite direction to that of a speed-specific effect. Imagery, on the other hand, again resulted in a distinct assimilation effect. Also, the effect of imagery was completely nullified when the participants were instructed to imagine the sequential motor action and to simultaneously pronounce words compatible with the imagined movement. Therefore, we conclude that the speed-specific interference effects in Experiment 1 cannot be attributed to verbal rehearsal of the steps.

General discussion

The experiments reported here investigated retroactive interference effects of imagined movement speed, as well as the functional equivalence between imagery and physical practice regarding movement speed. Together, the results of the two experiments showed: (1) that imagery of a specific movement speed interferes with the recall of movement speed at retention; (2) that the interference effect biases recall in the direction of the interpolated practice speed, thus causing an assimilation effect; (3) that when practising the sequential motor action in slow motion, imagery and physical practice yield similar retroactive interference, suggesting functional equivalence, whereas for the fast practice speed the effect of imagery was slightly less pronounced than the effect of physical practice; and (4) that vocalizing the rhythm of a sequential motor action does not appear to cause a speed-specific retroactive interference effect.

Our results on retroactive interference of imagined movement speed are consistent with the predictions of Lang's (1977, 1979, 1984, 1987) bio-informational theory. In line with Lang's theory, we hypothesized that an assimilation tendency would be found for movement speed in both directions (i.e. faster and slower). The results of Experiments 1 and 2 combined clearly support this predicted assimilation tendency for imagined movement speed. Within an informational network, speed might be encoded in three ways. First, creating a mental image of a slow or fast performed motor action will result in different response propositions. Secondly, movement speed might be encoded in the preparatory set by means of its deduced meaning or consequences. A movement performed or imagined at different speeds will result in different meaning propositions. Thirdly, performing a movement at two speeds will reveal different optical flow patterns. Visualizing these two flow patterns will result in two distinct sets of stimulus propositions.

Previous retroactive interference studies have shown that physical performance and imagery appear to be

functionally equivalent to movement amplitude or movement length (Johnson, 1982), movement pattern (Gabriele *et al.*, 1989; Hall *et al.*, 1995) and the amount of practice (Hall *et al.*, 1995). We have shown that this equivalence also largely holds for movement speed. This functional equivalence between imagery and overt motor performance is consistent with the similarity between the patterns and areas of cerebral activation observed during imagery of a motor action and during execution of the genuine overt motor action (Decety *et al.*, 1994; Jeannerod and Decety, 1995; Cunnington *et al.*, 1996; Sirigu *et al.*, 1996; Crammond, 1997).

The above-mentioned retroactive interference studies and the present study revealed that the effects of imagery and physical practice were practically equivalent. These results are surprising given that several reviews (e.g. Feltz and Landers, 1983; Murphy and Jowdy, 1992; Murphy, 1994) have concluded that imagery is less effective than physical practice in facilitating motor performance. Hall *et al.* (1992) discussed three factors influencing the effectiveness of imagery (i.e. the nature of the task, the type of imagery instructions and the participants' imagery ability). However, none of these factors provides a satisfactory explanation of the relatively strong effects found for imagery in interference studies. It appears that these studies have something else in common: imagery was applied to alter or convert the performance of a subsequent motor task. The relatively few retroactive interference studies appear to suggest that imagery is more effective when interfering with the performance of a subsequent motor action than when it is applied to facilitate motor performance. Janssen and Sheikh (1994) have indicated that the detrimental effect of negative images appears to be greater than the efficacy of positive images. According to Lang's bio-informational theory, imagery can modify the preparatory set to respond. When imagery is applied to a motor action in the same way as that action was or will be performed, the preparatory set will not be modified very much. On the other hand, when a motor image is different from the learned action, the preparatory set to respond is more likely to be modified.

The studies of Brooks (1968) and Williams *et al.* (1969) could provide an explanation why the verbal and combination groups in Experiment 2 did not show speed-specific interference. According to Williams *et al.* (1969), activities that deal with kinaesthetic memory show interference effects on the recall accuracy of movements and not on the recall of linguistic variables. Brooks (1968) noted a distinction between imagery and verbal processes by showing that pointing responses interfered more with visual imagery, whereas verbal responses interfered more with the verbal recall of sentences. A task will produce the largest and most

specific interference on another task if both tasks embrace the same modality and make use of the same kind of memory. Contrary to most dual-coding theories (e.g. Paivio, 1991; Annett, 1995), no additive effect was found of verbal rehearsal on imagery movement speed. When imagery was combined with verbal rehearsal, the constant error had an intermediate value. Although the results of the verbal groups point to an intriguing relation between movement imagery and verbal rehearsal, this is beyond the scope of the present study.

Johnson (1982), Gabriele *et al.* (1989) and Hall *et al.* (1995) used relatively simple, somewhat artificial motor tasks. The present study has shown that a more natural and complex action (a sequential motor action) can also exhibit interference effects with specific assimilation tendencies. It is likely, therefore, that retroactive interference owing to imagery will appear in a variety of practical settings and in everyday life. This is especially interesting in the light of recommendations to use motor imagery in slow motion: to enrich the content of an image (Andre and Means, 1986) or to 'replay' a previous performance to examine critical parts of it (Perry and Morris, 1995). In addition, slow motion imagery might be very useful in sports where participants tend to hurry during performance, such as golf. During such motor tasks, which are known to be sensitive to competition stress, the assimilation tendency of slow motion imagery might reduce the hastiness. However, the more common recommendation of sport psychologists to use imagery in real time appears justified. A sport psychologist implementing imagery or an athlete applying imagery should be cautious about the imagined scenes, because inappropriate images have 'the potential of producing significant decrements in performance' (Janssen and Sheikh, 1994, p. 17). To be most effective, the mental image should reflect in every respect, including the movement speed applied, the desired performance of the motor action.

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